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## EFFECTS OF BARE AND CASED EXPLOSIVES CHARGES ON REINFORCED CONCRETE WALLS

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### ABSTRACT

This paper represents a summary of an extensive investigation concerning the local effects of bare and cased explosives charges on reinforced concrete walls. The investigation includes a literature search as well as several test series. As a main result, charts for the prediction and comparison of the effects of bare and cased explosives charges are developed.

The most important conclusion is that cased charges result in perforation of reinforced concrete walls at distances up to ten times larger than bare charges of the same weight. Vice versa, given the charge weight and the distance, the wall thickness required to avoid perforation is up to three times larger for cased charges than it is for uncased charges. Hence, it becomes evident that simulating local effects of weapons with bare charges - as often done for practical reasons - may lead to considerable underestimation of the actual effects.

### 1. INTRODUCTION

In this paper the damage to reinforced concrete slabs from bare explosives charges and weapons detonating at or near such slabs is discussed.

Is this topic still of such interest as to give rise to a detailed investigation? The need for reliable data on the effects of explosives charges and weapons detonating close to walls is not new. However, it becomes of immediate interest in connection with some actual defense and safety problems.

As an example, a small free-standing ammunition magazine is shown in Figure 1. The ammunition stored therein might explode or otherwise be damaged by a hostile attack. In the course of analyzing survivability chances, the probable circular error (CEP) of the relevant weapons has to be compared with the size of the target area. But the virtual target area strongly depends on the distance to the building at which a detonating grenade or bomb can destroy the wall and possibly initiate a detonation

of the stored ammunition.

As another example, a safety problem within an ammunition factory can be mentioned. This was, in fact, the actual problem which stimulated our investigation (Figure 2). The question was whether or not a dividing wall, designed to withstand an uncased charge of 10 kg of TNT, could protect a workshop place from a detonating HE grenade of calibre 155 mm containing 6.8 kg of explosives.

Some data referring to these problems can be found in various handbooks and in the literature. Information, however, as to which cases are really referred to, is generally rather poor. In particular, it is not possible to make a distinct comparison between the effects of bare and cased charges. On the other hand, it was clear to us from a few earlier tests that casing does affect the resulting damage significantly.

With the purpose of improving our knowledge concerning this problem, an investigation was performed, including the following three steps:

- Existing data were gathered from earlier tests and from literature. A number of 87 tests was evaluated with respect to information regarding this problem.
- Three complementary test series including a total of 46 tests were conducted in order to allow for a systematic variation of parameters.
- Design charts, both for bare charges and cased charges, have been developed and compared to each other. Moreover, an extensive collection of photographs has been published. This might give a better insight into the actual phenomena than any theoretical model.

As the most important conclusion it has been recognized that cased charges can produce perforation of reinforced concrete walls, if detonating at distances of up to ten times larger from the wall than uncased charges of the same weight. In the case of the above-mentioned ammunition magazine, the distance from which a projectile or bomb detonating above ground can destroy an outer wall, determines

the size of the virtual target area. Thus, it is essential to realize the big difference in the destructive range of bare and cased charges.

In the case of the dividing walls in an ammunition factory, the wall designed to withstand 10 kg of uncased TNT proved to be inadequate for the 155 mm HE grenade. The grenade representing a cased charge of only 6.8 kg of explosives required a wall thickness of more than twice as much.

## 2. DEFINITION OF DAMAGE CATEGORIES

Damages on a reinforced concrete wall from near-by explosions may vary from minor cracks up to complete perforation. Figure 3 shows an overview of characteristic damages. For the assessment of the protection provided by a wall, damage effects at its back are most relevant. Three damage categories have been defined for the evaluation of the tests and other data:

Damage Category 0: No relevant damage at the back

Damage Category A: Moderate up to heavy spalling at the back

Damage Category B: Complete, open perforation

These categories are rather wide and do not represent a sophisticated system, but this grouping facilitates the placing of the observed individual damages in the groups themselves. These damage categories allow to draw conclusions with respect to the lethality of persons exposed behind a wall, or for a detonation's propagation to stored ammunition. Since such considerations usually have to be based on pragmatic approaches, a more detailed classification of the damage categories would not be useful.

## 3. COMPILATION OF THE EVALUATED TESTS

Number and type of test	Explosives Quantity	Distance r	Thickness of slab t
<b>Bare Charges</b>			
Own tests: 31	0.013 - 10 kg	0 - 1 m	0.1 - 0.4 m
From literature: 65	0.05 - 227 kg	0 - 1.2 m	0.09 - 1.1 m
<b>Cased Charges</b>			
Own tests: 15	0.37 - 6.85 kg	0 - 5 m	0.1 - 0.4 m
From literature: 22	0.2 - 22 kg	0 - 4 m	0.1 - 1.2 m

Using all 133 tests as data base, the variation of the following parameters has been investigated:

- Size of explosives charge; for explosives other than TNT, the TNT-equivalent for corresponding peak overpressure has been used.
- Charge weight to total weight ratio for cased charges
- Shape of charge
- Distance from center of charge to slab surface
- Thickness of concrete slab
- Reinforcement  $\mu$  (weight per volume)
- Concrete compression strength
- Damage category 0, A or B

In a couple of tests, additional parameters have been investigated such as initial velocity of wall-debris, their travel distance and mass. Furthermore, data from 12 earlier tests with bombs and grenades located at the wall surface below ground (i.e. tamped charges) have been included.

## 5. RESULTS OF THE INVESTIGATION

The previously mentioned tests have been evaluated systematically and design charts have been developed showing wall thickness versus scaled distance for the different damage categories. It was found that limited variation of concrete strength, reinforcement and charge to total weight ratio for cased charges did not strongly affect the results. But the observed damage was considerably more severe when the reinforcement of the concrete was less than a threshold value of about 50 kg/m<sup>3</sup>. On the other hand, the extent of damage attenuated for cased charges if the weight of the casing was less than 40 % of the total weight.

In Table 4 the parameter limits for the succeeding design charts are given. Selecting data from tests which meet these limits allows to obtain clear results.

Figure 5 shows the design chart for bare explosives charges. In this chart the two axes are the scaled wall thickness and the scaled distance of the charge from the wall respectively. The lower line represents the threshold between perforation and spalling. The upper line correspondingly represents the limit between the spalling category and the one for minor damage. The two threshold lines are parallel in this log/log-plot, i.e. they are separated by a constant factor. Regarding the wall thickness, the factor between the beginning of perforation and spalling at the back is always two for bare charges.

Figure 6 shows the corresponding plot for cased charges, i.e. grenades and bombs. The threshold between the different damage categories is again quite sharp. There is one particular data-point from an older test with 50 kg bombs shown, which does not fit into its category. At a scaled distance of  $1.5 \text{ m/kg}^{1/3}$  only minor damage was reported, whereas the chart indicates that spalling or perforation should occur. Next to this point, at a scaled distance of about  $1.6 \text{ m/kg}^{1/3}$  a test with a heavily cased 105 mm HE projectile produced perforation slightly above the threshold line. The analysis of the test has led to the conclusion that damage to reinforced concrete walls from cased charges is dominated by the impact of fragments, particularly at large scaled distances. Of course, the ratio of net explosives charge weight to total weight is important for the damage of light cased charges in the transition range between bare and cased charges. This parameter has not been studied in more detail yet.

All data shown in Figure 6 are based on tests with non-tamped grenades and bombs. A comparison with data from tamped cased charges shows good agreement for weapons which have contact with the exposed wall. Tamping has, therefore, only little effect on the damage produced by cased charges with wall contact.

In Figure 7 the damaging effects of bare and cased charges are compared. For a given wall thickness, the distance required to avoid perforation is four to ten times larger for cased charges than it is for uncased charges of the same explosive weight. Vice versa, given the charge weight and the distance, the wall thickness required to avoid perforation is up to three times larger for cased than for uncased charges. Hence, it becomes evident that simulating local effects of weapons with bare charges - as often done in tests for practical reasons - may lead to a considerable underestimation of the actual effects. Figure 8 gives a visual impression of the damage produced by two different types of charges placed at the same distance from a reinforced wall.

This investigation was sponsored by the Defense Technology and Procurement Group, TA 6, of the Swiss Federal Department of Defense. The results including numerous pictures from tests are published in the following reports which are available upon request:

- Amt für Bundesbauten: "Sprengversuche an Betonwänden", Ernst Basler & Partners, B 922.10, February 1980
- Gruppe für Rüstungsdienste, TA 6: "Sprengversuche an Betonplatten", Ernst Basler & Partners, B 3113-1, June 1981
- Gruppe für Rüstungsdienste, TA 6: "Lokale Schadenwirkungen an Betonplatten durch Sprengladungen", Ernst Basler & Partners, B 3113.10-1, Sept. 82

### Example: Target Areas for Different Damage Categories

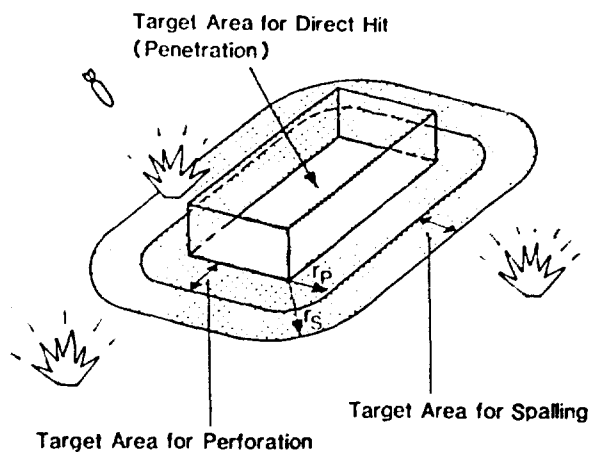


Figure 1: Assessment of target-area for above-ground building for different damage categories as a basis for estimating the probability of survival for a given type of attack.

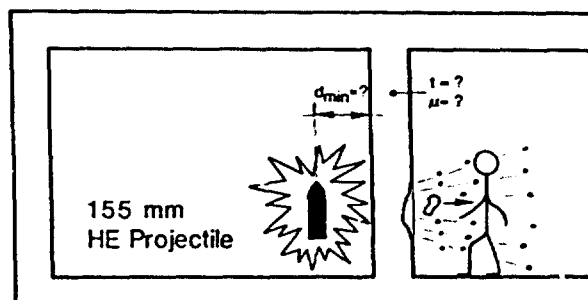
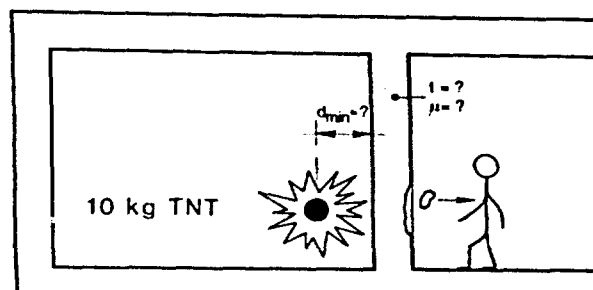


Figure 2: Example: Design of a Dividing Wall in an Ammunition Factory

### Definition of Damage Categories







Distance of Explosion from Wall	Characteristic Damages	Defined Damage Category
	No relevant damage, cracks ev. small crater	O
	crater, deflections and cracks	
	Spalling on back	A
	Heavy spalling on back	
	Perforation	B
	Heavy Perforation	

Figure 3: Definition of Damage-Categories

### Range of Explosives Charges Covered by Design Charts

#### Charge Weight

- Uncased Charge 0.01 kg - 200 kg
- Cased Charge, net 0.3 kg - 30 kg

Total Weight 0.5 kg - 50 kg

Charge Weight Ratio 13 % - 60 %

Distance from Target contact up to 1 m/kg<sup>1/3</sup>

Thickness of Concrete Slab  $t$  0.1 m - 1.2 m

Reinforcement  $\bar{\mu}$  50 kg/m<sup>3</sup> - 150 kg/m<sup>3</sup>

Concrete Strength  $\beta_w$  20 N/mm<sup>2</sup> - 55 N/mm<sup>2</sup>

Figure 4: Range of Parameter Covered by Design Charts

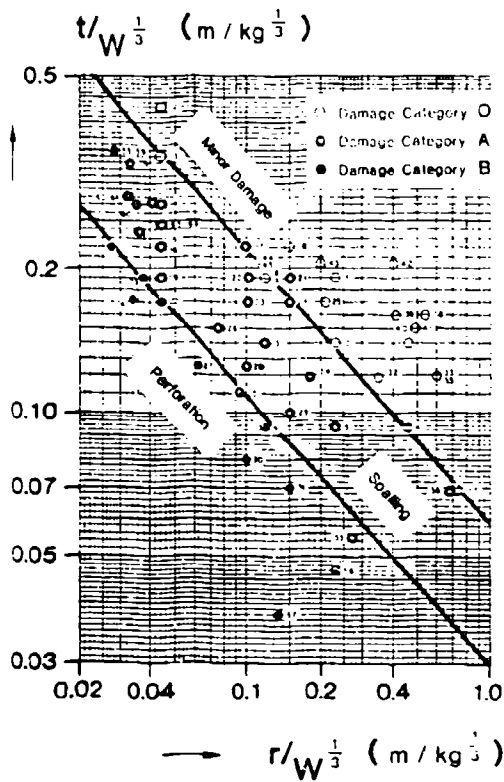


Figure 5: Damage to Reinforced Concrete Walls caused by Detonation of Uncased Explosives Charges

( $r/W^{1/3}$  = Scaled Distance;  
 $t/W^{1/3}$  = Scaled Wall Thickness)

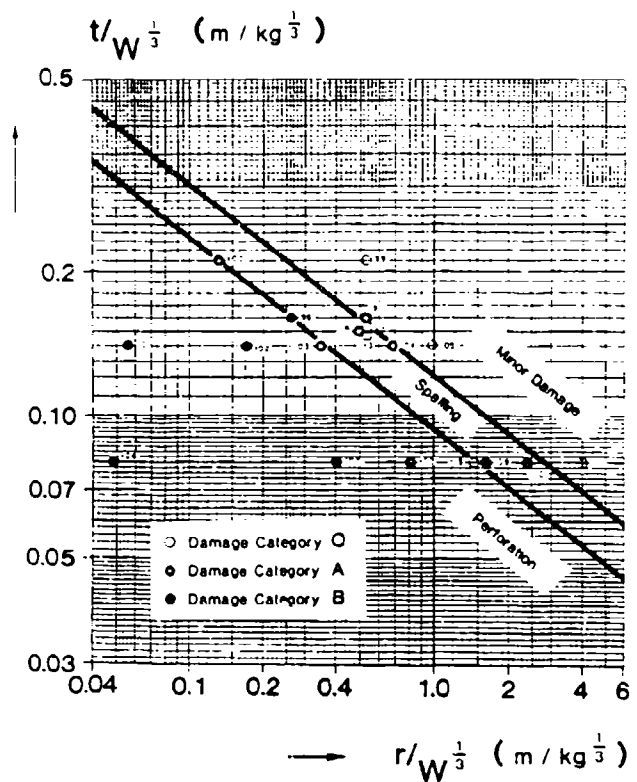


Figure 6: Damage to Reinforced Concrete Walls caused by Detonation of Cased Explosives Charges

( $r/W^{1/3}$  = Scaled Distance;  
 $t/W^{1/3}$  = Scaled Wall Thickness)

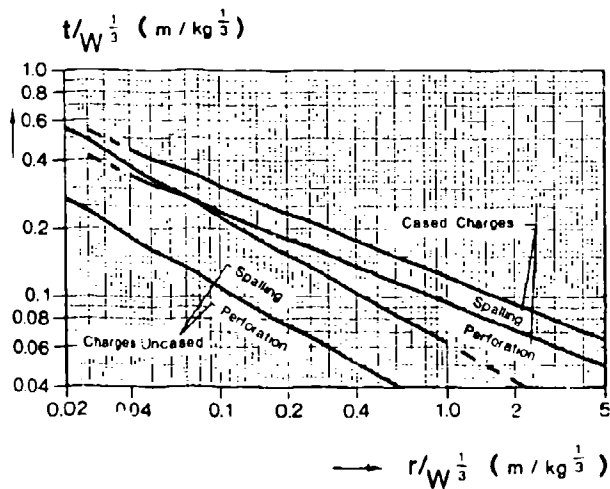


Figure 7: Comparison of Damage Caused by Uncased and Cased Explosives Charges

## Before Test

## After Test

### Bare Charge

10 kg TNT

Distance  $r = 0.5$  m

Wall Thickness  $t = 0.3$  m

Back of exposed wall shows minor cracks



### Cased Charge

15.5 cm (6.85 kg TNT)

Distance  $r = 0.5$  m

Wall Thickness  $t = 0.3$  m

Exposed wall completely destroyed

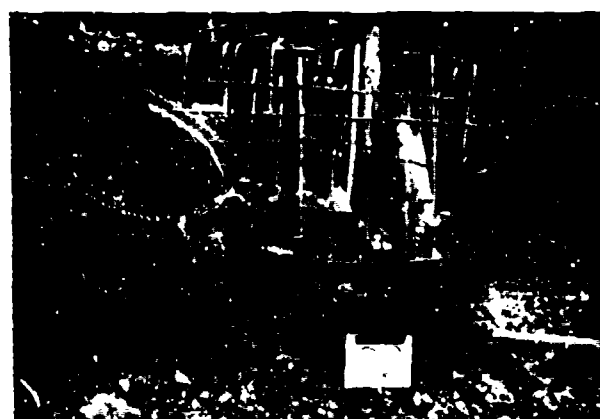
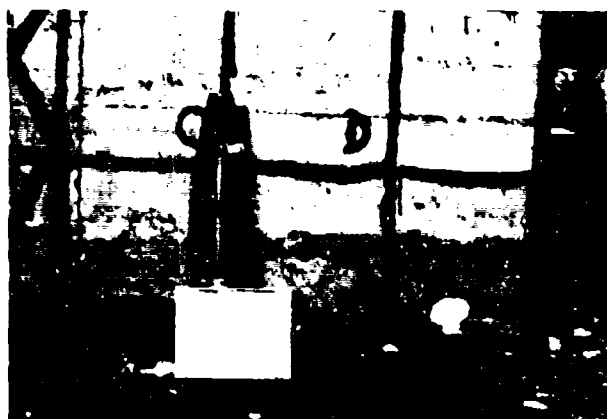


Figure 8: Visual comparison of the effects of bare and cased charges

